IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re application of
Kazuyuki Tadatomo et al.
Serial No. 09/787,502
Filed March 16, 2001
For : SEMICONDUCTOR LIGHT RECEIVING ELEMENT

Group Art Unit: 2815
Examiner: ORTIZ, EDGARDO

#6/Translation
4-11-02
R. Drake

TRANSLATOR'S DECLARATION

Honorable Commissioner of Patents and Trademarks
Washington, D.C. 20231

Sir:

I, Ritsuko Arimura, declare:

That I am well acquainted with both the Japanese and English languages;

That the attached document represents a true English translation of Japanese Patent Application No. 10-265516 filed on September 18, 1998; and

That I further declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issuing thereon.

Signed this 26th day of February, 2002.

Ritsuko Arimura

Ritsuko Arimura

(Translation)

PATENT OFFICE

JAPANESE GOVERNMENT

This is to certify that the annexed is a true copy of the following application as filed with this Office.

Date of Application : September 18, 1998

Application Number : 265516/1998

Applicant(s) : MITSUBISHI CABLE INDUSTRIES, LTD.
NIKON CORPORATION

Commissioner, Patent Office

【Document】 Petition for Patent
【Reference Number】 A3769
【Submission Date】 September 18, 1998
【To】 Commissioner of the Patent Office
【International Classification】 H01L 31/00
【Title of the Invention】 Photoconductive Element
【Number of Claims】 4
【Inventor】
【Address】 c/o Itami Factory of MITSUBISHI CABLE INDUSTRIES, LTD., 3, Ikejiri 4-chome, Itami-shi, Hyogo, Japan
【Name】 Kazuyuki Tadatomo
【Inventor】
【Address】 c/o Itami Factory of MITSUBISHI CABLE INDUSTRIES, LTD., 3, Ikejiri 4-chome, Itami-shi, Hyogo, Japan
【Name】 Hiroaki Okagawa
【Inventor】
【Address】 c/o Itami Factory of MITSUBISHI CABLE INDUSTRIES, LTD., 3, Ikejiri 4-chome, Itami-shi, Hyogo, Japan
【Name】 Yoichiro Ouchi
【Inventor】
【Address】 c/o Itami Factory of MITSUBISHI CABLE INDUSTRIES, LTD., 3, Ikejiri 4-chome, Itami-shi, Hyogo, Japan
【Name】 Masahiro Koto
【Inventor】
【Address】 4-22, Shibata 1-chome, Yokkaichi-shi, Mie, Japan
【Name】 Kazumasa Hiramatsu
【Inventor】
【Address】 c/o NIKON CORPORATION, Sagamihara Plant, 10-1, Azamizodai 1-chome, Sagamihara-shi, Kanagawa, Japan
【Name】 Yutaka Hamamura
【Inventor】
【Address】 c/o NIKON CORPORATION, Ohi Plant, 6-3, Nishiohi 1-chome, Shinagawa-ku, Tokyo, Japan
【Name】 Sumito Shimizu
【Applicant】
【Identification Number】 000003263
【Name】 MITSUBISHI CABLE INDUSTRIES, LTD.
【Applicant】
【Identification Number】 000004112
【Name】 NIKON CORPORATION

【Agent】
【Identification Number】 100080791
【Patent Attorney】
【Name】 Hajime Takashima
【Telephone Number】 06-6227-1156

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【Document】 SPECIFICATION

【Title of the Invention】 Photoconductive Element

【What is Claimed is】

【Claim 1】 A photoconductive element comprising at least a first conductivity type i layer made from a GaN group crystal as a light receiving layer wherein one surface of the light receiving layer is a light receiving surface on which the light to be received enters, an ohmic electrode of one polarity is formed to permit an entry of the light to be received and an ohmic electrode of the other polarity is formed on the other surface of the light receiving layer directly or via a first conductivity type and low resistance GaN group crystal layer.

【Claim 2】 The photoconductive element of claim 1, wherein the ohmic electrode of one polarity is formed as a transparent electrode to permit an entry of the light to be received.

【Claim 3】 The photoconductive element of claim 1, wherein the ohmic electrode of one polarity is an opaque electrode and an electrode area covered with the electrode and an incident area not covered with the electrode are formed on the light receiving surface to permit entry of the light to be received.

【Claim 4】 The photoconductive element of claim 1, wherein the ohmic electrode of the other polarity is formed via a first conductivity type and low resistance GaN group crystal layer, the afore-mentioned low resistance GaN group crystal layer and the light receiving layer are successively formed on a crystal substrate, an upper surface of the low resistance GaN group crystal layer is partially exposed, and the ohmic electrode of the other polarity is formed on this exposed surface.

【Detailed Description of the Invention】

【Technical Field to which the Invention pertains】

The present invention relates to a technical field of a

semiconductor light receiving element, particularly a photoconductive element (photoconductor).

【Prior Art】

A photoconductive element is a light receiving element wherein a current is taken out by utilizing a phenomenon (photoconductive effect) that the conductivity of the crystals changes due to the carrier generated in a light receiving layer (generally, a semiconductor crystal layer made to be a high-resistance layer) by light excitation, based on which the receipt of the light is detected.

A conventional photoconductive element, as shown in Fig. 4, has a constitution wherein both positive and negative ohmic electrodes 12, 13 are disposed facing each other on the surface of the light receiving layer 11 as a light receiving surface. The light L to be received is capable of exciting a semiconductor crystal layer 11 and generates a carrier. Due to the generation of the carrier, the conductivity between the electrodes varies. By such constitution wherein the voltage is applied between the both electrodes 12 and 13, the entry of the light to be received can be detected as a change in the current.

【Problems to be Solved by the Invention】

According to the above-mentioned structure of a photoconductive element, the generated carrier moves between the electrodes along the light receiving surface. The present inventors have found it problematic.

That is, the light receiving surface is literally a surface of or an interface between materials forming the light receiving layer, and is constantly exposed to a light having a severe energy. As a result, the light receiving surface and the surface layer thereof are subject to various quality problems, such as contamination from the surrounding environment during practical use, degradation of the semiconductor surface due to the incident light and the like, which are caused by the light receiving surface being an

interface. With the structure of a conventional element wherein the carrier moves on the surface layer along the light receiving surface, therefore, the recombination velocity of the carrier dramatically changes, lowering the reproducibility of the detection results, and impairing the reliability of a photodetecting element.

To cope with the increasing density of integrated circuits, a step-and-repeat photolithographic system with demagnification for forming a fine circuit pattern therefor is required to have an ability to draw more finely at higher resolution. Therefore, a change to use KrF excimer laser device (a wavelength of 248 nm) or ArF excimer laser device (a wavelength of 193 nm) has been contemplated as the laser source used for drawing.

In the above-mentioned step-and-repeat photolithographic system with demagnification, a part of the laser beam is received by a light receiving element, and changes in the output and the like are monitored. The above-mentioned light receiving element is exemplified by a photodiode (PD) made from Si group semiconductor materials. However, when the laser beam has a powerful energy, like the light having a shorter wavelength of 248 nm or 193 nm, a conventionally used Si group PD shows dramatic degradation, thus necessitating frequent replacement for a new one.

An object of the present invention is to provide a photoconductive element having a new structure capable of decreasing the contamination of and a degrading influence on a light receiving surface, besides the superior resistance also to a light having a wavelength in the ultraviolet range.

【Means of Solving the Problems】

The photoconductive element of the present invention is characterized by the following.

(1) A photoconductive element comprising at least a first conductivity type i layer made from a GaN group crystal as a light receiving layer wherein one surface of the light

receiving layer is a light receiving surface on which the light to be received enters, an ohmic electrode of one polarity is formed to permit an entry of the light to be received and an ohmic electrode of the other polarity is formed on the other surface of the light receiving layer directly or via a first conductivity type and low resistance GaN group crystal layer.

(2) The photoconductive element of (1) above, wherein the ohmic electrode of one polarity is formed as a transparent electrode to permit an entry of the light to be received.

(3) The photoconductive element of (1) above, wherein the ohmic electrode of one polarity is an opaque electrode and an electrode area covered with the electrode and an incident area not covered with the electrode are formed on the light receiving surface to permit entry of the light to be received.

(4) The photoconductive element of (1) above, wherein the ohmic electrode of the other polarity is formed via a first conductivity type and low resistance GaN group crystal layer, the afore-mentioned low resistance GaN group crystal layer and the light receiving layer are successively formed on a crystal substrate, an upper surface of the low resistance GaN group crystal layer is partially exposed, and the ohmic electrode of the other polarity is formed on this exposed surface.

The GaN group crystal as used in the present invention is a compound semiconductor defined by the formula $In_XGa_YAl_ZN$ ($0 \leqq X \leqq 1$, $0 \leqq Y \leqq 1$, $0 \leqq Z \leqq 1$, $X+Y+Z=1$). The i layer is a general name for a low concentration layer, referring either to an n-type low concentration layer (called ν layer and written as n^-) or a p-type low concentration layer (called π layer and written as p^-).

【Action】

The photoconductive element according to the present invention is the same as the one explained as regards the conventional art for the basic mechanism of detecting the

receipt of light, wherein a photoconductive effect is utilized to take out a current, based on which the receipt of light is detected.

The important characteristic of the photoconductive element according to the present invention is a constitution where only an ohmic electrode of one polarity is formed on the light receiving surface of the light receiving layer, and an ohmic electrode of the other polarity is formed on the back of the light receiving surface directly or via other crystal layer (high concentration layer of the same conductive type as the light receiving layer). By this constitution, a carrier generated in the light receiving layer due to the incident light to be received moves not only on the surface along the light receiving surface, but in the thickness direction of the light receiving layer. In other words, since the area occupied by the surface layer becomes smaller and, conversely, the area occupied by the high quality depth increases, both relative to the carrier motion path, the recombination period of the carrier can be further stabilized.

【Mode of Embodiment of the Invention】

A photoconductive element of the present invention has a first conductivity type (n-type in this Figure) i layer made from a GaN group crystal, as a light receiving layer 1, as shown in Figs. 1(a), 1(b). One surface of the light receiving layer 1 is a light receiving surface 1a that the light L to be received enters. The light receiving surface 1a has an ohmic electrode 2 of one polarity. The ohmic electrode 2 is formed to permit entry of the light L to be received. The other surface 1b of the light receiving layer has an ohmic electrode 3 of the other polarity via the same conductive type and low resistance GaN group crystal layer 4 as the light receiving layer, thus constituting the photoconductive element. The ohmic electrode 3 of the other polarity may be directly formed on the other surface 1b of

the light receiving layer. Hereinafter, a GaN group crystal layer 4 for forming an ohmic electrode of the other polarity is also simply referred to as a contact layer.

The range of wavelength of the light to be received is determined according to the band gap of the GaN group crystal used for the light receiving layer. It is a light having a shorter wavelength than red light (near wavelength 656 nm). In particular, ultraviolet light, such as the light having a wavelength of 248 nm (KrF excimer laser), the light having a wavelength of 193 nm (ArF excimer laser) and the like, have an intense energy, which causes many problems for conventional elements. By the use of a GaN group material to receive such ultraviolet light, a superior light receiving element having an improved resistance to ultraviolet light, as compared to a conventional PD and the like made from an Si group semiconductor material, can be obtained.

The conductive type of the light receiving layer need only be a first conductivity type (i.e., either p-type or n-type). To increase an S/N ratio by lowering the dark current, however, it is preferably an n-type low concentration layer (ν layer) or an i layer. The light receiving layer has a carrier concentration range of from about 1×10^{13} cm^{-3} to 1×10^{17} cm^{-3}.

The thickness of the light receiving layer is not limited, but it is preferably about 0.1 μm - 5 μm, because a carrier needs to be generated in the entirety of the layer by light absorption.

The material of the light receiving layer need only be a GaN group crystal, but InGaN is preferable for the light having a wavelength longer than 365 nm, and GaN and AlGaN are preferable for the ultraviolet light having a wavelength shorter than 365 nm.

The both electrodes are ohmic electrodes so that the variation of resistance due to a photoconductive effect can be detected with high sensitivity. An ohmic electrode refers

to one wherein metal-semiconductor contact does not show rectification properties (irrespective of the direction of the voltage to be applied), and contact resistance can be almost ignored (see, for example, "Semiconductor Device", S. M. Sze (translated by Yasuo Nannichi et al.), Sangyo Tosho (first edition, 3rd printing, page 163).

The ohmic electrode to be formed on the light receiving surface should be formed in such a way that the light to be received can enter the receiving layer. Examples of such electrode include a transparent electrode as shown in Fig. 1(a). Even in the case of an opaque electrode, as shown in Fig. 1(b), an excess incident amount of the light L to be received is secured by forming an incident area not covered with the electrode on a light receiving surface 1a, based on which the incident area and an area covered with the electrode can be balanced.

As the ohmic electrode to be formed on the light receiving surface, when the light receiving layer is an n-type low concentration layer, a transparent electrode, such as Au (thickness 50 nm)/Ti (thickness 100 nm) and the like, can be used, and the opaque electrode is exemplified by Au (thickness 1 μm)/Ti (thickness 100 nm) and the like. In addition, when the light receiving layer is a p-type low concentration layer, the transparent electrode is exemplified by Au (thickness 50 nm)/Ni (thickness 100 nm) and the like, and the opaque electrode is exemplified by Au (thickness 500 nm)/Ni (thickness 100 nm) and the like.

In the case of a low carrier concentration, a practical problem of unfeasible ohmic contact exists. To solve this, a layer having a free electron (or hole) concentration of about 1×10^{18} cm^{-3} and a thickness of about 10 nm - 50 nm is preferably inserted as a layer for ohmic contact (referred to as an ohmic contact layer), between the light receiving layer and electrode. For a conventional type, wherein a pair of electrodes is formed on a light receiving surface and a

current flows along the light receiving surface, the ohmic contact layer needs to be separated by cutting between electrodes. In contrast, such layer can be left without cutting in the present invention.

The arrangement pattern of the ohmic electrode formed on a light receiving surface may include a part or the entirety of the light receiving surface, in the case of a transparent electrode. In the case of an opaque electrode, moreover, an electrode area covered with the electrode and an incident area not covered with the electrode are formed. For example, a comblike, lattice or other electrode pattern can be formed.

The other ohmic electrode is formed on the back of the light receiving layer directly or via a contact layer, as mentioned above. To compensate for the thickness of the light receiving layer, the latter embodiment is preferable. Even in this case, a laminate is preferable wherein contact layer 4 and light receiving layer 1 are successively grown on the base crystal substrate 5, as shown in Figs. 1(a), (b). A different GaN group crystal layer may be also formed as necessary between the crystal substrate and contact layer. When the crystal substrate 5 is an insulator like a sapphire substrate, a preferable embodiment includes an upper side surface of the contact layer 4 exposed as shown in Fig. 1, and the other ohmic electrode formed on the exposed surface.

The contact layer is preferably of the same conductive type as the light receiving layer, and preferably has low resistance, i.e., a carrier concentration range of from about 1×10^{17} cm^{-3} to 1×10^{19} cm^{-3}.

A contact layer preferably has a thickness of about 1.0 μm - 5.0 μm to secure crystallinity of the light receiving layer.

While there are a number of combinations of the materials for light receiving layer and contact layer, examples thereof (light receiving layer material/contact

layer material) include (n^- -GaN/n^+ -GaN), (n^- -AlGaN/n^+ -GaN), (n^- -AlGaN/n^+ -AlGaN), (n^- -InGaN/n^+ -GaN), (n^- -GaN/n^+ -AlGaN) and the like.

The crystal substrate may be any as long as a GaN group crystal can be grown, and is exemplified by sapphire, quartz, SiC etc. generally used for growing a GaN group crystal. Particularly, a sapphire substrate (C face, A face), a 6H-SiC substrate, more particularly sapphire substrate (C face) are preferable. Moreover, a buffer layer of ZnO, MgO, AlN and the like may be formed on the surface of such materials to alleviate the differences in the lattice constant with GaN group crystal, and also the coefficient of thermal expansion.

In the embodiments shown in Fig. 1, the shape of the element as a whole may be a combination of rectangle and column, forming a step-like shape in only one direction, as shown in Fig. 2(a), or a step-like shape in all directions, as shown in Fig. 2(b). The shape is appropriately determined in consideration of feasibility of production, preferable properties and the like. In the case shown in Fig. 2(b), the electrode 3 to be formed on the upper surface of the contact layer 4 may surround the outer periphery of the element or may be formed partially.

【Examples】

Example 1

In this Example, a photoconductive element, which comprised an electrode as shown in Fig. 1(a) and an element having a shape shown in Fig. 2(b), was prepared.

An n-GaN layer (thickness 3 μm, dopant Si, carrier concentration 1×10^{18} cm^{-3}) was grown on a sapphire substrate (C face) 5 via a GaN buffer layer (not shown) to give a contact layer 4, and an n^- -GaN layer (thickness 3 μm, dopant Si, carrier concentration 1×10^{15} cm^{-3}) was grown thereon to give a light receiving layer 1, and then an n-GaN layer (thickness 50 nm, dopant Si, carrier concentration 1×10^{18} cm^{-3}) was grown to give an ohmic contact layer (not shown).

A transparent ohmic electrode, Al (thickness 50 nm)/Ti (thickness 50 nm), was formed on a light receiving surface 1a via an ohmic contact layer, and the outer periphery was etched by RIE to only the depth of 2.2 μm, leaving the central part intact to expose the contact layer 4. As an ohmic electrode, Al (thickness 500 nm)/Ti (thickness 10 nm) was formed on the exposed surface to give a photoconductive element.

As the light to be received, a light at various wavelengths shorter than 450 nm was irradiated, and the light receiving sensitivity was examined. As a result, as shown with the curve ① drawn with a solid line in the graph of Fig. 3, the curve rose from the proximity to 365 nm and was found to show flat properties to the light having a wavelength shorter than that.

Example 2

In the same manner as in Example 1 except that the material of the light receiving layer was $Al_{0.1}Ga_{0.9}N$, and an ohmic electrode to be formed on a light receiving layer was an opaque electrode shown in Fig. 1(b) in this Example, a photoconductive element was prepared.

The ohmic electrode on the light receiving layer was Al (thickness 2 μm)/Ti (thickness 2 μm). The electrode drawn on the light receiving surface had a pattern comprising one strip conductor as a trunk line and a number of strip conductors branching therefrom, thereby forming a "comblike" electrode.

In the same manner as in Example 1, the light receiving sensitivity was examined. As a result, as shown with the curve ② drawn with a broken line in the graph of Fig. 3, the curve rose from the proximity to 340 nm and was found to show flat properties to the light having a wavelength shorter than that.

【Effect of the Invention】

As explained in the foregoing, the photoconductive

element of the present invention has a structure allowing the generated carrier to move in the thickness direction of the light receiving layer. As a result, crystal conditions, such as contamination, degradation and the like of the proximity of the light receiving surface, do not have a great influence on the sensitivity. In addition, because a GaN group crystal is used for the light receiving element, a superior light receiving element improved in ultraviolet resistance, as compared to a conventional PD and the like made from an Si group semiconductor material, can be obtained.

【Brief Description of the Drawings】

Fig. 1 is a sectional view of an exemplary structure of the photoconductive element according to the present invention, wherein Fig. 1(a) shows an embodiment of a transparent electrode and Fig. 1(b) shows an embodiment of an opaque electrode. Hatching is applied only to the electrodes for identification.

Fig. 2 is a perspective view showing the entire shape of the photoconductive element according to the present invention.

Fig. 3 is a graph showing the properties of the light receiving sensitivity of the light receiving elements prepared in Examples 1, 2 and shows the relationship between the wavelength of the irradiated light and the light receiving sensitivity. In this Figure, the curve ① drawn with a solid line shows Example 1, the curve ② drawn with a broken line shows Example 2, and the axis of ordinates showing the light receiving sensitivity is an arbitrary scale.

Fig. 4 is a schematic view showing the structure of a conventional photoconductive element.

【Explanation of the Symbols】

1: light receiving layer

1a: light receiving surface

1b: other surface of light receiving layer

2: ohmic electrode of one polarity

3: ohmic electrode of the other polarity

4: contact layer

5: crystal substrate

【Document】 Abstract

【Summary】

【Problem】 Provision of a photoconductive element having a new structure capable of decreasing the contamination of and a degrading influence on a light receiving surface, besides the superior resistance also to UV light.

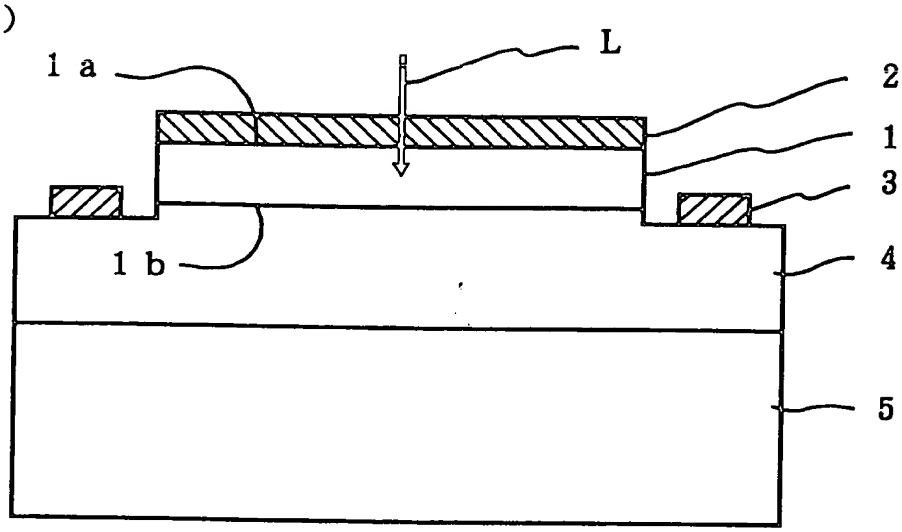
【Solving Means】 With a first conductivity type (particularly n-type) i layer made from a GaN group crystal as a light receiving layer 1, and one surface of the light receiving layer 1 as a light receiving surface 1a that the light L to be received enters, an ohmic electrode 2 of one polarity is formed on the light receiving surface 1a. The ohmic electrode 2 is formed such that the amount secured of the light L to be received is more than necessary. The ohmic electrode 3 of the other polarity is formed on the other surface 1b of the light receiving layer directly or via a first conductive type and low resistance GaN group crystal layer (contact layer) 4 to give a photoconductive element. As a result, a generated carrier moves in the thickness direction of the light receiving layer to alleviate the influence caused by contamination and degradation of the light receiving surface.

【Main Drawing】 Fig. 1

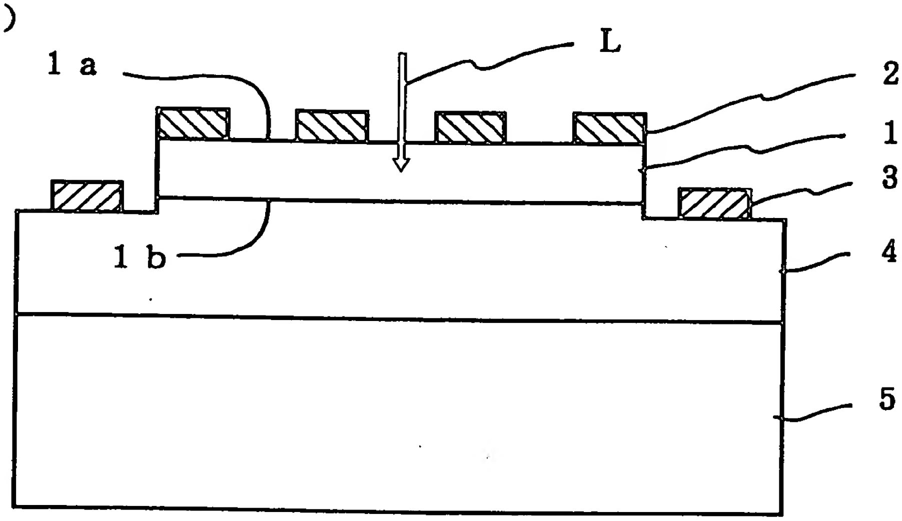
【Document】 DRAWING

【Fig. 1】

(a)



(b)



1: light receiving layer

1a: light receiving surface

1b: other surface of light receiving layer

2: ohmic electrode of one polarity

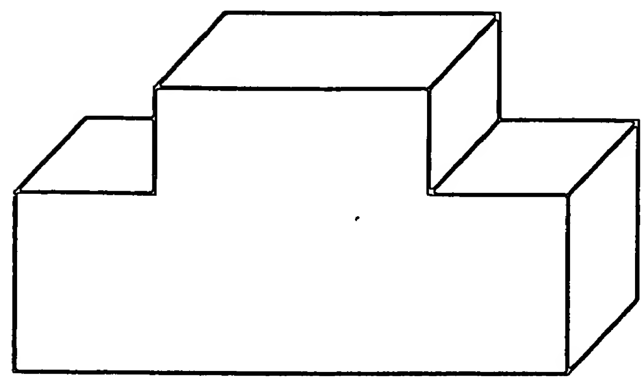
3: ohmic electrode of the other polarity

4: contact layer

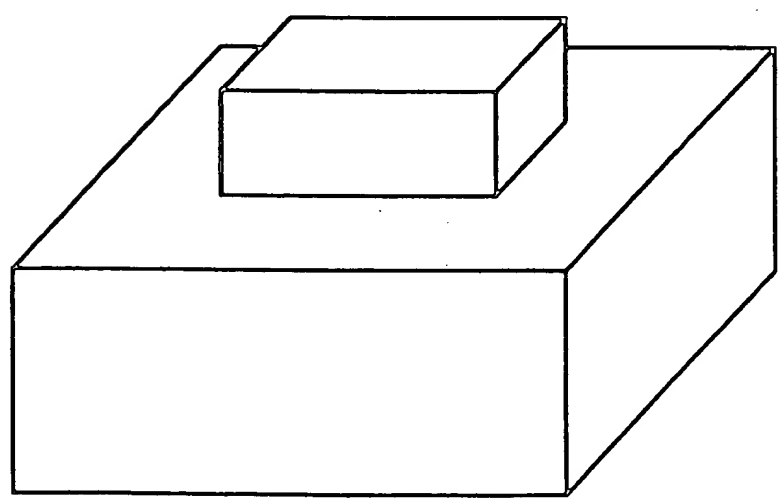
5: crystal substrate

【Fig. 2】

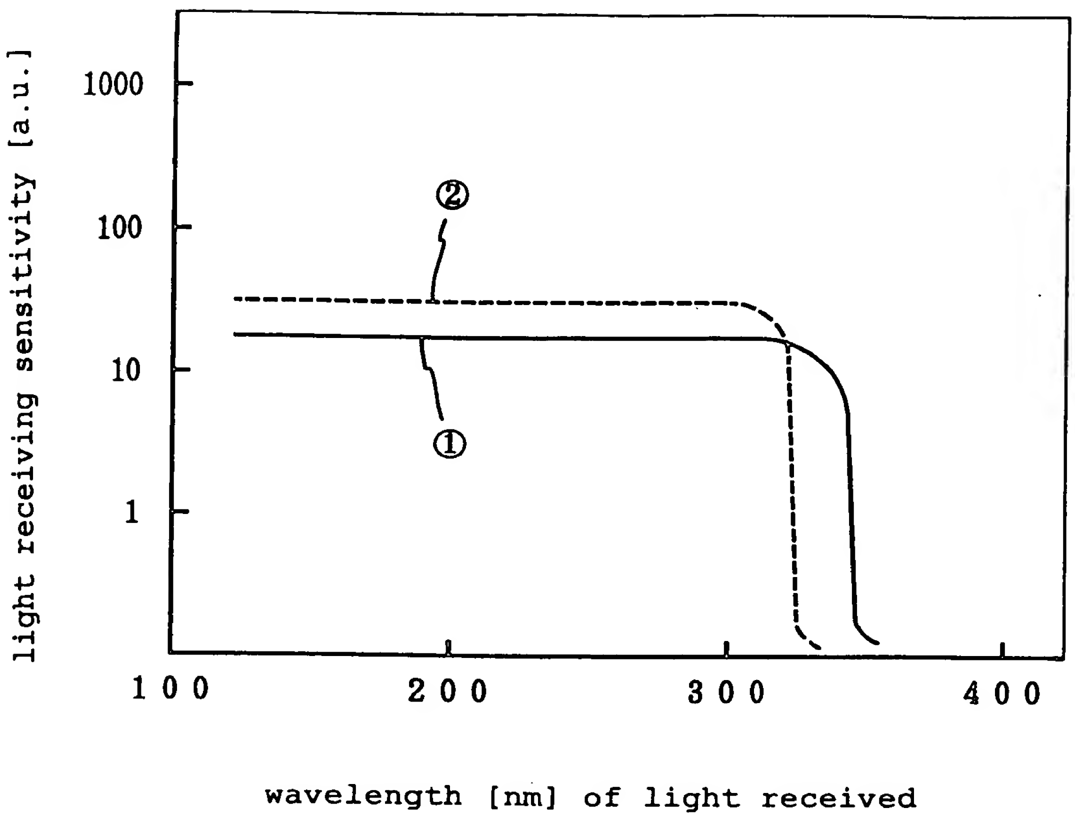
(a)



(b)

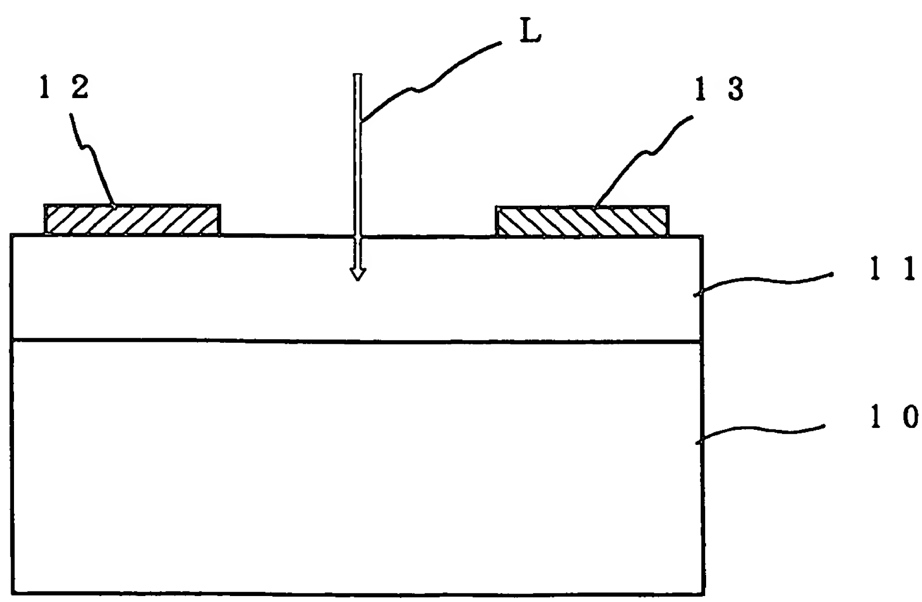


【Fig. 3】



light receiving sensitivity [a.u.]
1000
100
10
1
②
①
100
200
300
400
wavelength [nm] of light received

【Fig. 4】



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TRANSLATOR'S DECLARATION

Honorable Commissioner of Patents and Trademarks
Washington, D.C. 20231

Sir:

I, Ritsuko Arimura, declare:

That I am well acquainted with both the Japanese and English languages;

That the attached document represents a true English translation of Japanese Patent Application No. 10-265506 filed on September 18, 1998; and

That I further declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issuing thereon.

Signed this 26th day of February, 2002.

Ritsuko Arimura

Ritsuko Arimura